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Hyperlordosis is associated with facet joint pathology at the lower lumbar spine

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Abstract: STUDY DESIGN:: A retrospective study. OBJECTIVE:: Our study opted to clarify the remaining issues of lumbar lordosis (LL) in regard to (1) its physiologic values, (2) age, (3) gender, (4) facet joint (FJ) arthritis and orientation using CT scans. SUMMARYOF BACKGROUND DATA:: Recent studies have questioned whether LL really decreases with age, but study sample sizes have been rather small and mostly been based on X-rays. Since hyperlordosis increases the load transferred through the FJs, it seems plausible that hyperlordosis may lead to FJ arthritis at the lower lumbar spine. METHODS:: We retrospectively analyzed CT scans of 620 individuals, with a mean age of 42.5 (range, 14-94) years, who presented to our traumatology department and underwent a whole body CT scan, between 2008 and 2010. LL was evaluated between the superior endplates of L1 and S1. FJs of the lumbar spine were evaluated for arthritis and orientation between the L2 and S1. RESULTS:: (1) The mean LL was 49.0° (SD 11.1°, range 11.4-80.1°). (2) LL increased with age and there was a significant difference in LL in our age groups (30, 31-50, 51-70 and 71 y) (P=0.02). (3) There was no significant difference in LL between females and males (50° and 49°) (P=0.17). (4) LL showed a significant linear association with FJ arthritis (P=0.0026, OR=1.022 [1.008-1.036]) and sagittal FJ orientation at L5/S1 (P=0.001). In a logistic regression analysis the cut-off point for LL was 49.4°. CONCLUSION:: This is the largest CT-based study on LL and FJs. LL significantly increases with age. As a novelty finding, hyperlordosis is significantyly associated with FJ arthritis and sagittal FJ orientation at the lower lumbar spine. Thus hyperlordosis may present with back pain and patients may benefit from surgical correction, for example in the setting of trauma.

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Hyperlordosis Is Associated With Facet Joint Pathology At The Lower Lumbar Spine

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Running Title: Hyperlordosis and Facet Joint Pathology

Study Design: A retrospective study.

Key Words: Lumbar Lordosis, Hyperlordosis, Facet Joint Arthritis, Facet Joint Orientation

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The authors declare that they have no competing interests.

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Abstract

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Objective. Our study opted to clarify the remaining issues of lumbar lordosis (LL) in regard to (1) its physiologic values, (2) age, (3) gender, (4) facet joint (FJ) arthritis and orientation using CT scans.

Summary of Background Data. Recent studies have questioned whether LL really decreases with age, but study sample sizes have been rather small and mostly been based on X-rays. Since hyperlordosis increases the load transferred through the FJs, it seems plausible that hyperlordosis may lead to FJ arthritis at the lower lumbar spine.

Methods. We retrospectively analyzed CT scans of 620 individuals, with a mean age of 42.5 (range, 14-94) years, who presented to our traumatology department and underwent a whole body CT scan, between 2008 and 2010. LL was evaluated between the superior endplates of L1 and S1. FJs of the lumbar spine were evaluated for arthritis and orientation between the L2 and S1.

Results.(1) The mean LL was 49.0° (SD 11.1°, range 11.4 – 80.1°). (2) LL increased with age and there was a significant difference in LL in our age groups (≤ 30, 31-50, 51-70 and ≥ 71 years) ($p = 0.02$). (3) There was no significant difference in LL between females and males (50° and 49°) ($p = 0.17$). (4) LL showed a significant linear association with FJ arthritis ($p = 0.0026$, OR = 1.022 [1.008-1.036]) and sagittal FJ orientation at L5/S1 ($p = 0.001$). In a logistic regression analysis the cut-off point for LL was 49.4°.

Conclusion. This is the largest CT-based study on LL and FJs. LL significantly increases with age. As a novelty finding, hyperlordosis is significantyly associated with FJ arthritis and sagittal FJ orientation at the lower lumbar spine. Thus hyperlordosis may present with back pain and patients may benefit from surgical correction, for example in the setting of trauma.

Introduction

Humans are the only species with the ability to maintain an erect, bipedal position [1]. Sequential, divergent curves play a major role in our upright position. Lumbar lordosis (LL) is one of these and unique to humans [2]. It is able to tolerate large compressive vertical loads [3, 4]. Anatomically, spinal back extension, i.e. hyperlordosis increases the load transferred through the facet joints (FJ) [5]. It locks them in a specific position for better stability by contact of the superior and inferior articular processes [6]. It also compresses an interfering pars interarticularis if there is a lack of pyramidal interfacet distance from L1 to S1, especially between L4/5 and L5/S1 [7].

Mean values for LL range around 48 – 61° [8-12]. However, sample sizes have been rather small and mostly based on X-rays instead of CT scans . A recent study [13] has challenged the common opinion of a decreasing LL with age-related changes [14, 15], such as atrophy of the extensor muscles [16] and suggested the need for further studies [13], which showed that LL may actually increase with age [11, 12, 17]. LL has mostly been described [14, 18, 19] without a difference in genders, but one study has found an increased LL in females [20].

Recent studies [2, 21] have suggested an association of sagittal alignment and variations in degenerative spinal patterns, even though this has not been proven sufficiently [22-24]. Unbalanced spinal load distribution has been reported to ultimately cause FJ arthritis [25]. Almost 75% of total LL is contributed by the lower levels L4 – S1and FJ arthritis is more common at the lower lumbar spine because the lowest three FJs carry the highest loads [9, 26-31]. Thus, it seems plausible that hyperlordosis may lead to FJ arthritis at the lower lumbar spine. For example, it has been proposed that hyperlordosis may ultimately cause FJ arthritis due to higher contact force on the FJs [2]. Furthermore, the relationship of LL and FJ orientation as well as tropism has only been investigated [32] at the cervical, but not at the lumbar level. Therefore, there is a lack of evidence-based literature on these issues.

Our study opted to clarify the remaining issues of LL in regard to (1) its physiologic values, (2) age, (3) gender, (4) FJ arthritis and orientation using CT scans.

Materials and Methods

The study has been approved by the local research ethics review committee (KEK-ZH-Nr.2011-0507). We retrospectively analyzed CT scans of 620 individuals, with a mean age of 42.5 (range, 14-94) years, who presented to our traumatology department and underwent a whole body CT scan, including the pelvis and lumbar spine, between 2008 and 2010. A dual-source computed tomography scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany) was used [33]. Our study utilized CT scans instead of plain radiographs or MRIs, because they are more accurate in displaying FJs on axial planes [34, 35].

(1) We evaluated CT scans of the lumbar spine between L1 und S1. LL was evaluated on median sagittal slides by measuring the angle between the superior endplates of L1 and S1, based on the definition of Stokes and the Scoliosis Research Society [18, 19] (Fig. 1). (2) Individuals were grouped into those ≤ 30 years, 31-50 years, 51-70 years and ≥ 71 years. (3) Gender was also evaluated. (4) FJs of the lumbar spine were evaluated between the second lumbar and the first sacral level [36] (Fig. 3). Axial planes with the largest intersecting set of the superior and inferior FJ process were chosen. Assessment of FJ arthritis was carried out as previously described in similar studies, where a grading scale described by Pathria was used [37, 38]. Grade 0 (normal) indicates a normal FJ, whereas grades 1 – 3 display increasing signs of FJ arthritis with each grade including signs of the lower grade. Grade 1 (mild) shows joint space narrowing, grade 2 (moderate) demonstrates sclerosis and grade 3 (severe) reveals osteophytes [39]. FJ orientation in the axial plane was evaluated by measuring the angle between the midline of the sagittal plane and the midline of the FJ as described by Schuller et

al. [40] and Mahato[41]. FJ orientation was calculated by averaging the angle between the right and left side of the FJs. The FJ orientation was labeled as coronal if angles were > 45°, sagittal if angles were ≤ 45° and anisotropic if one side was over and the other side under 45°[42].

All statistical analysis was performed by the Institute for Social and Preventive Medicine, Division of Biostatistics at the University of Zuerich. This study is an observational study. Significant difference was assumed if $p < 0.05$. To assess the association between the numerical measure (1) LL and the variables (2) age, (3) gender and (4) FJ orientation, different statistical models were applied. For each of (2), (3) and (4) a one way ANOVA was applied with (1) as outcome and the p-value resulting from a F-test. A proportional odds model was applied in regard to the ordinal outcome FJ arthritis (4) and the explanatory variable (1).

Results

Of our 620 individuals, 617 were evaluated on sagittal and axial planes of CT scans of the lumbar spine from L1 – S1. Three (0.5%) individuals could not be evaluated for LL because spondylodesis had been performed or appropriate planes had not been reconstructed adequatly.

(1) The individuals in our study displayed a mean LL of 49.0° (SD 11.1°, range 11.4 – 80.1°).

(2) There was significant evidence that LL increases with age ($p = 0.02$) The mean value for LL in the age group ≤ 30 years was 47.8° (SD 10.8°, range 18.9-78.4°) compared to 48.5° (SD 10.5°, range 19.1-77.6°) in the age group between 31-50 years, 50.2° (SD 10.8°, range

14.2-71.6°) in the age group between 51-70 years and 52.5° (SD 13.5°, range 11.4-80.1°) in the age group ≥ 71 years (Fig. 4).

(3) There was no significant difference in LL between females and males (50° and 49°) ($p = 0.17$). Our study included 202 (32%) females and 418 (68%) males.

(4) LL showed a significant and linear association with FJ arthritis ($p = 0.0026$, OR = 1.022 [1.008-1.036]) (Fig. 5). Individuals with increased LL are more prone to a higher degree of FJ arthritis (Fig. 6-7). In a logistic regression analysis the cut-off point for LL was 49.4°. There was proof that LL significantly correlates to the FJ orientation at L5/S1 ($p = 0.001$) (Fig. 8). Increased LL was associated with more sagittal FJ orientation at this level (Fig. 7). However, LL did not correlate with the FJ orientation at the other lumbar levels (p = 0.17, 0.59 and 0.50 at L2/3, L3/4 and L4/5).

Discussion

Our study investigated the largest sample of CT scans from different individuals in the literature in regard to LL and (1) its physiologic values, (2) age, (3) gender, (4) FJ arthritis and orientation. We were able to show that the (1) mean value for LL on CT scans ranges around 49°. LL was significantly correlated with (2) age, but not with (3) gender. We also found a significant linear relationship between LL and (4) FJ arthritis as well as sagittal FJ orientation at the lower lumbar spine, namely L5/S1. LL and FJ orientation at the upper lumbar spine were not significantly correlated.

Limitations of our study attribute to the fact that all individuals presented to a trauma department. Even though a selection bias may be assumed, we did not include individuals with a fracture of the spondylodesis or fracture of lumbar spine. Furthermore, we did not pay special attention to degenerative disc disease since this has been investigated in previous studies [43-45]. Due to the retrospective nature of this study, we were not able to investigate which individuals showed clinical signs of hyperlordosis and FJ arthritis. Nevertheless, radiologic proof of FJ arthritis has not been clearly associated with back pain at all times [46-48]. We did not specify the exact level or side of FJ arthritis since all levels and sides seemed to be affected in a similar fashion, with lower levels being slightly more frequently affected [49]. Even though our study included a similar number of individuals under and over 40 years, it comprised nearly twice as many males, which may be attributed to the fact that males are injured and present to a traumatology department more often [50].

(1) Our results for the mean value of LL (49°) is in line with previous studies [8-12] (Fig. 1). Remarkably, we were able to include a much larger sample size, namely 617 patients. In a random subset of 191 individuals from the Framingham study by Kalichman et al. [13], the mean LL, measured from L1 to S1 on CT scans was 47°. Reviewing lateral X-rays of 28 patients, the mean LL, measured from L1 to S1, was 50° +/- 14° in a study by Gardocki et al. [9].

(2) In our study, LL significantly increased with age (Fig. 4). This is the largest study of only a few studies [13, 17], investigating age-related changes in LL with CT scans. Kalichman et al. [13] recently investigated 191 participants of the Framingham study and did not find a change in LL with age. This challenged the common opinion of a decreasing LL with age-related changes [14, 15], such as atrophy of the extensor muscles [16] and suggested the need for further studies [13]. Our results are in line with another study of 200 supine lumbar spines on CT scans by Aylott et al. [17], who described an increasing lumbar lordosis with age of 0.1° per year. This may be explained by biomechanical analysis of the spine, which has shown that LL is capable of bearing large compressive loads [3]. Vertical compression forces measured up to 1000 Newtons for an individual of 70 kg [5]. LL increases with growth until adulthood and mean values for adults range around 47 – 61° [10-12].

(3) We did not find a gender related difference (Fig. 5). This is similar to previous radiographic studies[19]. Using a measuring technique for LL through assessment of the superior endplates of L1 and S1, as described by the Stokes and the Scoliosis Research Society [18], no difference in LL was reported in a previous 3-D radiographic study by Janssen et al. [19] comparing asymptomatic and young lumbar spines of females and males. In the study mentioned above by Korovessis et al. [14], there was no gender difference either. This contrasts another evaluation of LL by Vialle et al. [20], assessing the endplates of L1 and L5 by an older 2-D radiographic study of 300 asymptomatic adults, where females were found to have increased LL.

(4) Our study presents the first evaluation of LL and FJ arthritis on CT scans [2]. As a novelty finding, we were able to demonstrate a significant linear relationship between LL and FJ arthritis as well as sagittal FJ orientation at the lower lumbar spine, namely L5/S1 (Fig. 2, 6-8). This indicates that individuals with increased LL, especially those with LL of ≥ 49.4° are more prone to a higher degree of FJ arthritis at this level.

Previous studies [22-24] have only been based onplain radiographs and have yielded confusing results. Papadakis et al. [22] did not find a difference in LL and FJ arthritis in 112 females. Fahrni and Trueman [23] suggested that lower LL is associated with less lumbar degenerative disease. Harrison et al. [24] even found an association between hypolordosis and lumbar degeneration. This ambiguity may be overcome by using CT scans, which deliver more precise images of the FJs, as was done in our study.

Low back pain may be caused by hyperlordosis as well as FJ arthritis and lower lumbar segments play a crucial role [27, 28]. Almost 75% of total LL is contributed by the lower levels L4 – S1 [9, 29]. Yang et al. [5] and Roussouly et al. [2] reported that hyperlordosis lead to an increased contact force on FJs. In a cadaveric study of 18 lumbar spines by Adams et al. [29], compression forces were applied to an intervertebral disc and its adjacent vertebrae.

While erect, FJs transmitted shear forces and carried about a sixth of the spine's weight, while intervertebral discs absorbed the majority. Notably, the lowest three FJs were shown to carry the highest loads. This explains why FJ arthritis also increases in a cephalocaudal fashion [14, 30, 31]. Therefore, it seems reasonable that hyperlordosis, which mainly affects the lower levels, leads to pathology of the lower lumbar FJs.

In regard to the association of LL and FJ orientation only one study [32] have been carried out, but at the cervical spine. Studying 252 X-rays of the cervical spine, Harrison et al. [32] did not find a correlation between LL and FJ orientation. Looking at the lumbar spine, our results indicated an association between LL and sagittal FJ orientation at the lower level. There was no relationship between LL and FJ orientation at the upper levels. Cohen et al. [51] reported that FJ orientation planes differ at various lumbar levels, with more sagittal orientation for resistance against axial rotation in the upper in contrast to a more coronal orientation for resistance against flexion in the lower lumbar segments. Considering that increased LL is associated with FJ arthritis, it seems logical that FJs display a pathologic sagittal orientation at the lower lumbar spine.

Conclusion

Mean values for LL on CT scans ranges around 49°. Up to date, this is the largest CT-based study showing that LL is significantly correlated with age. LL does not have a significant gender predeliction. As a novelty finding, LL is significantly and linearly associated with FJ arthritis as well as sagittal FJ orientation at the lower lumbar spine. LL ≥ 49.4° is associated with a significantly higher risk of FJ arthritis. LL and FJ orientation at the upper lumbar spine are not significantly correlated. Thus hyperlordosis may present with back pain and patients may benefit from surgical correction, for example in the setting of trauma.

List of Abbreviations

LL: Lumbar Lordosis.

FJ: Facet Joint.

No Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

…: Conception and design, acquisition of data, analysis and interpretation of data, drafting the manuscript, revision of the manuscript, final approval of the version to be published. …: Acquisition of data. …: Revision of the manuscript. …: Conception and design, analysis and interpretation of data, revision of the manuscript, final approval of the version to be published.

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Figure Legends

Fig. 1. Lumbar lordosis (LL)

LL was evaluated on median sagittal slides by measuring the angle between the superior endplates of L1 and S1, based on the definition of Stokes and the Scoliosis Research Society [18, 19]

Fig. 2. Facet Joint (FJ) Arthritis

Assessment of FJ arthritis was carried out as previously described in similar studies, where a grading scale described by Pathria was used [44, 45]. Grade 0 (normal) indicates a normal facet joint, whereas grades 1 – 3 display increasing signs of FJ arthritis with each grade including signs of the lower grade. Grade 1 (mild) shows joint space narrowing, grade 2 (moderate) demonstrates sclerosis and grade 3 (severe) reveals osteophytes [46].

Fig. 3. Facet Joint (FJ) Orientation

FJ orientation in the axial plane was evaluated by measuring the angle between the midline of the sagittal plane and the midline of the FJ as described by Schuller and Mahato [47, 48]. FJ orientation was calculated by averaging the angle between the right and left side of the FJs.

Fig. 4. Lumbar Lordosis (LL) and Age

Seperating individuals into four age groups (≤ 30, 31 – 50, 51 – 70 and > 70), there was significant evidence that LL is related to age ($p = 0.02$).

Fig. 5. Lumbar Lordosis (LL) and Gender

There was no significant difference in LL between females and males (50° and 49°) ($p = 0.17$)

Fig. 6. Lumbar Lordosis (LL) and Facet Joint (FJ) Arthritis

LL showed a significant and linear association with FJ arthritis ($p = 0.0026$, OR = 1.022 [1.008-1.036]).

Fig. 7. Lumbar Lordosis (LL) and Facet Joint (FJ) Arthritis and Orientation

LL showed a significant and linear association with FJ arthritis ($p = 0.0026$, OR = 1.022 [1.008-1.036]) and sagittal FJ orientation at L5/S1 ($p = 0.001$).

Fig. 8. Lumbar Lordosis (LL) and Facet Joint (FJ) Orientation

LL was significantly and linearly correlated with sagittal FJ orientation at L5/S1 ($p = 0.001$) but not at other levels. Increased LL was associated with more sagittal FJ orientation at L5/S1.

Figure (TIF or EPS Only!!! Resolution of at least 300 dpi!)
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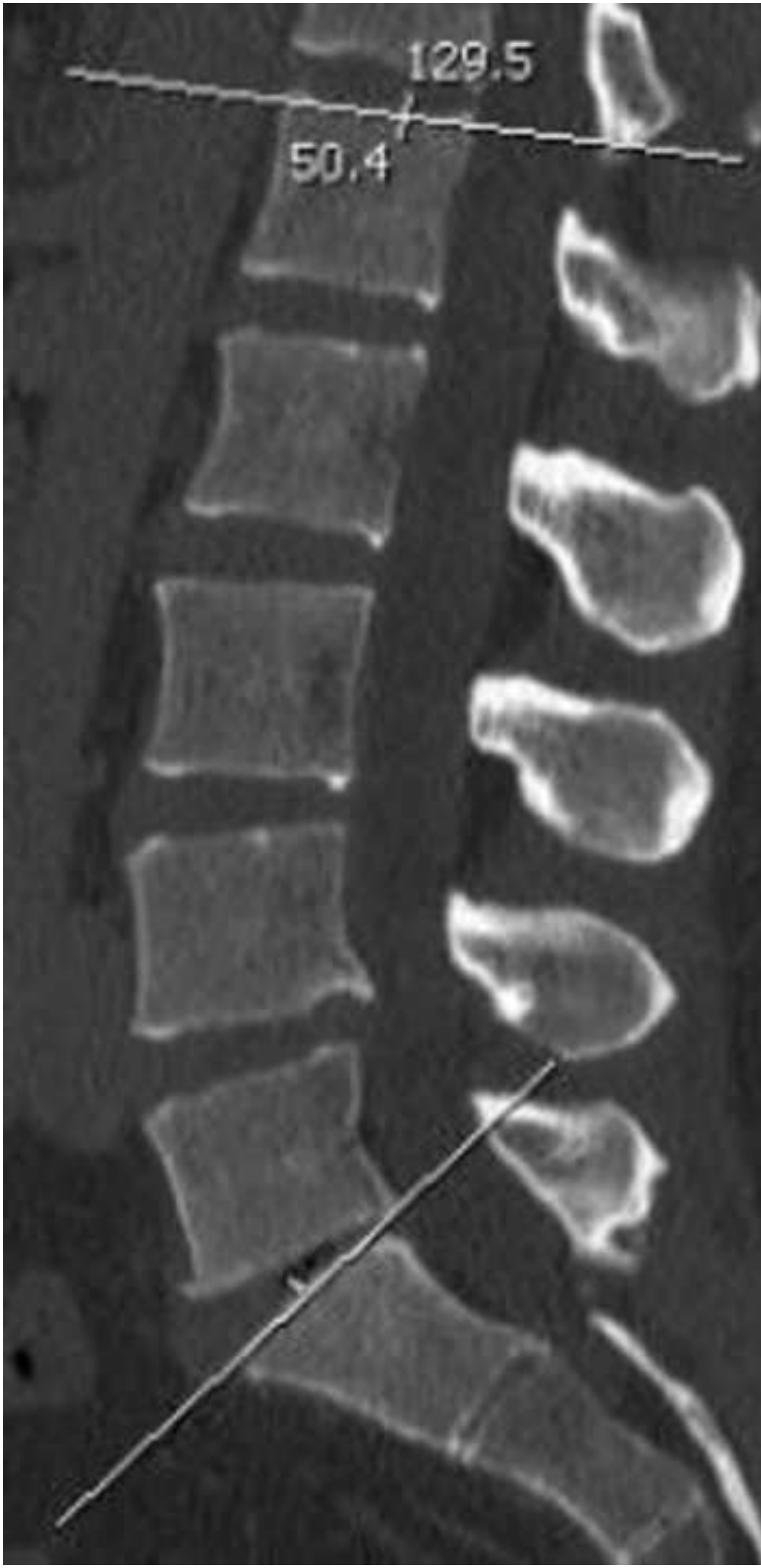

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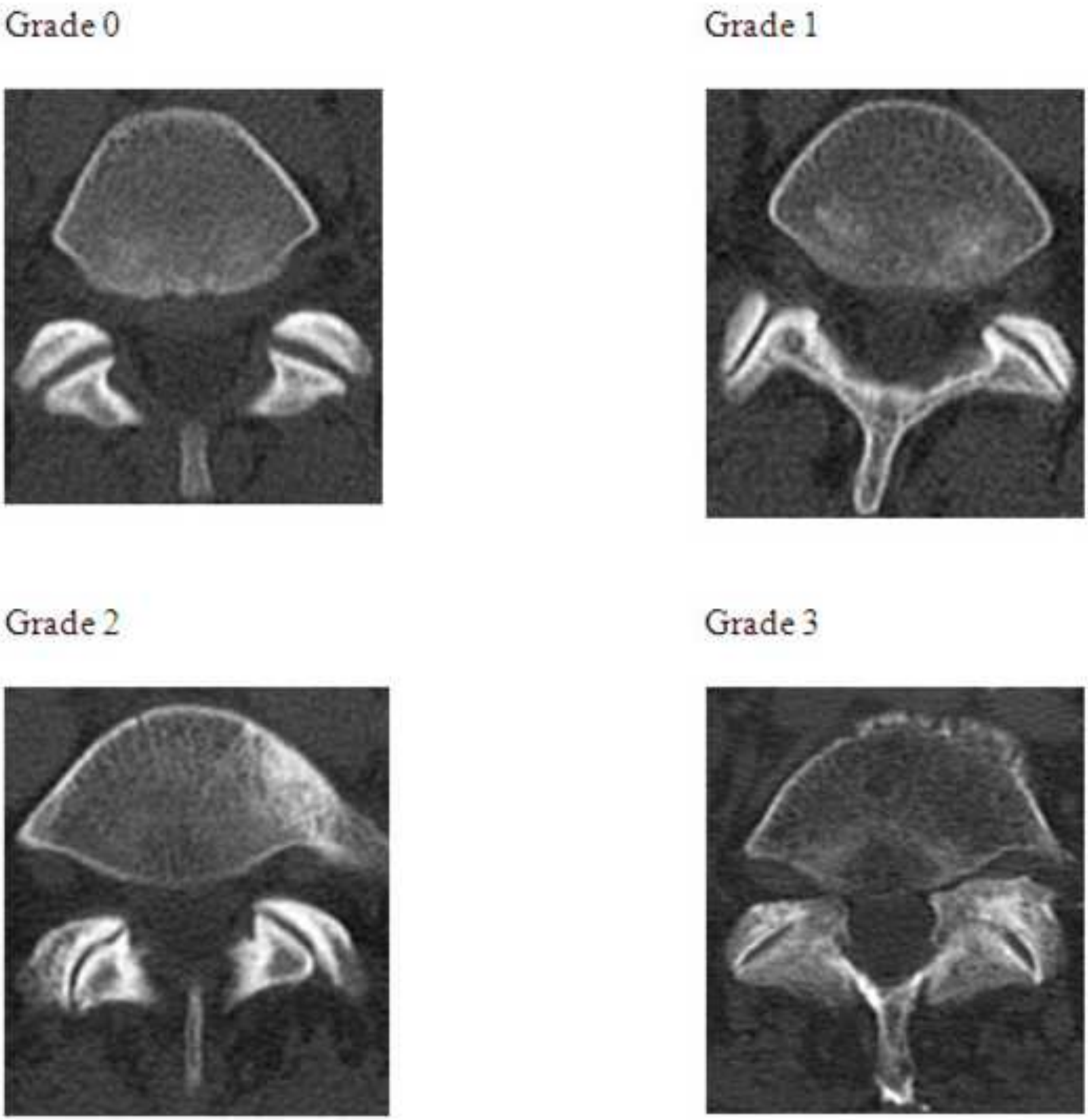
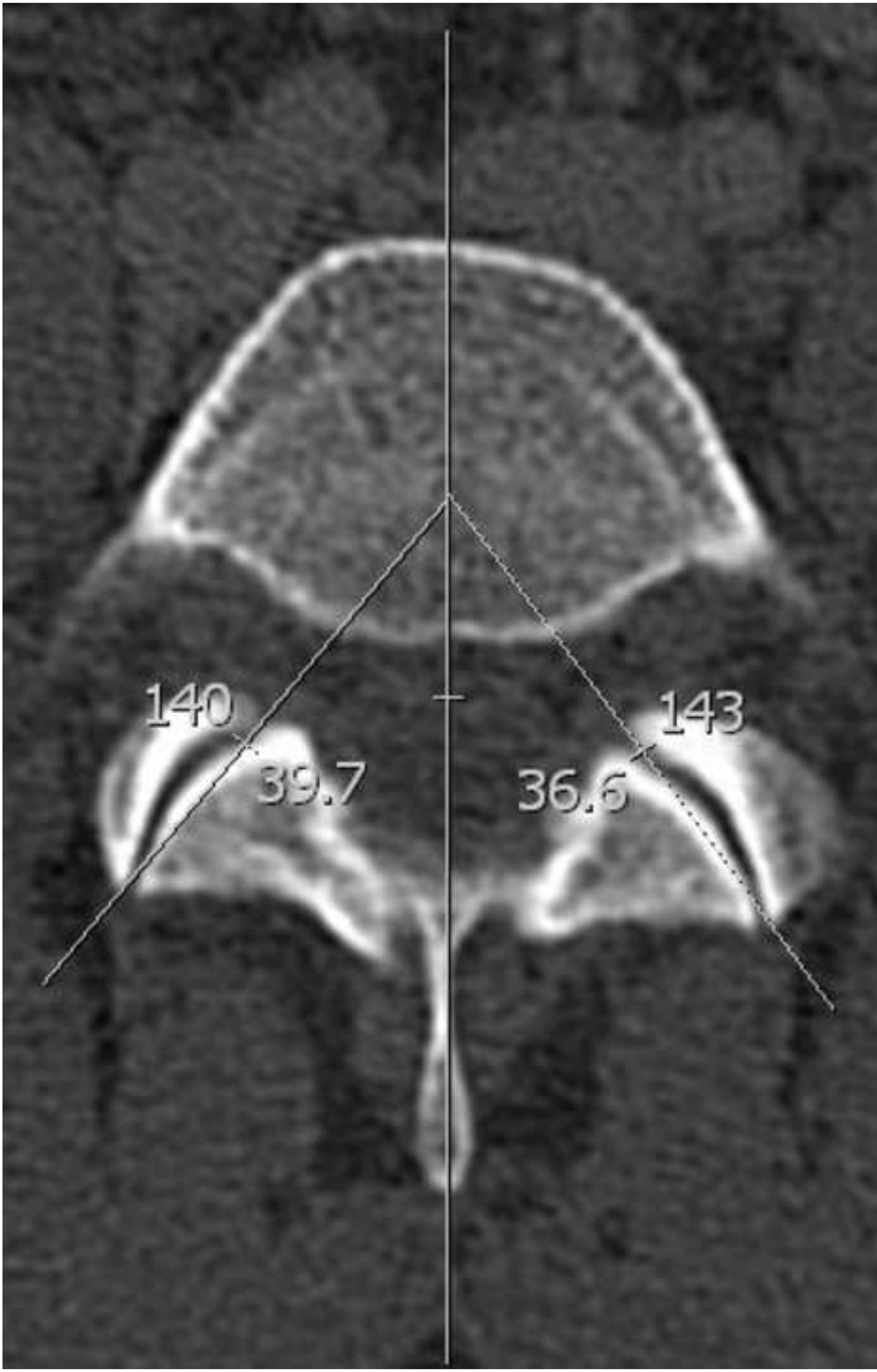
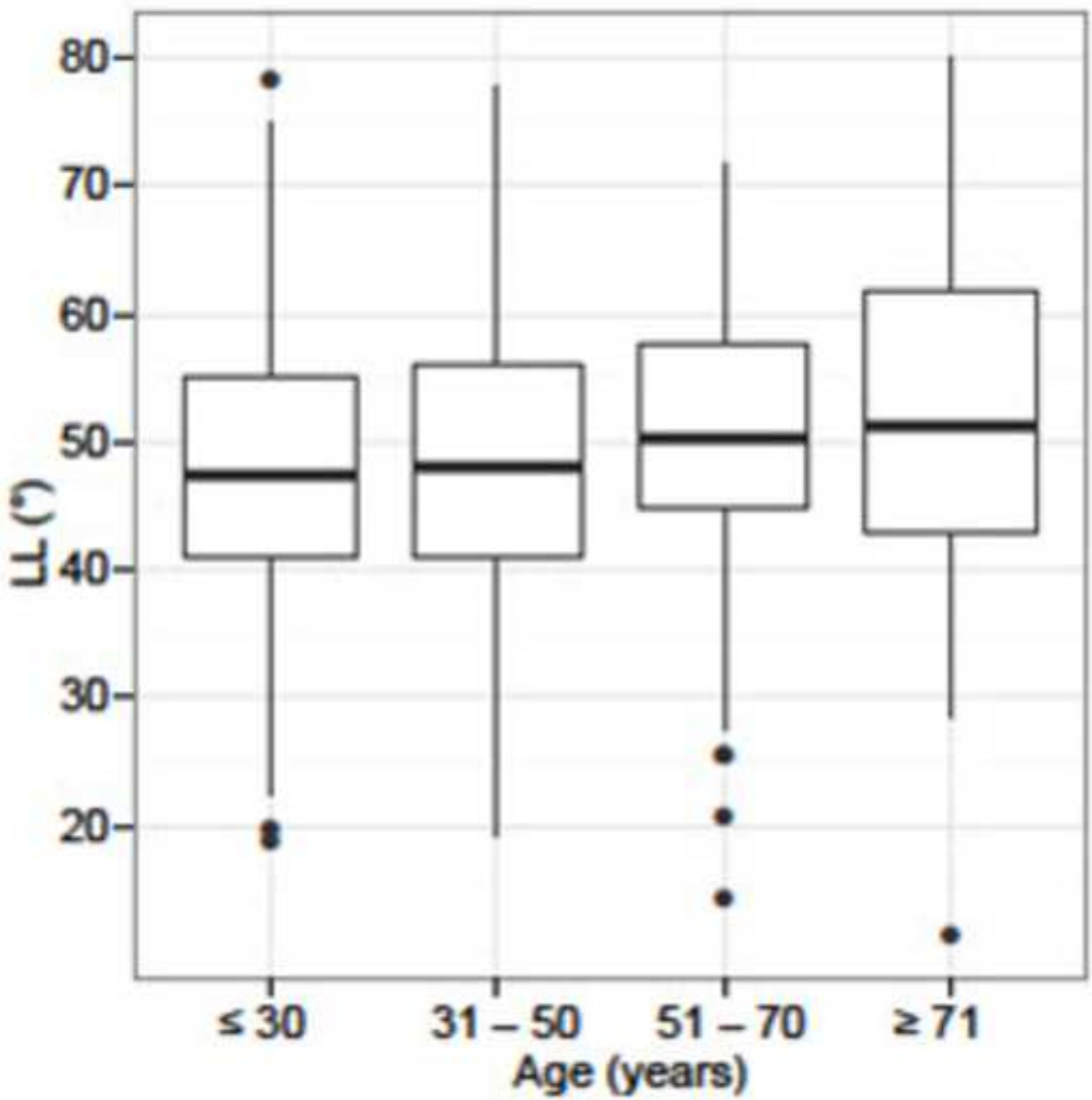



140
39.7
143
36.6


80
70
60
50
40
30
20
LL (°)
≤ 30
31 – 50
51 – 70
≥ 71
Age (years)

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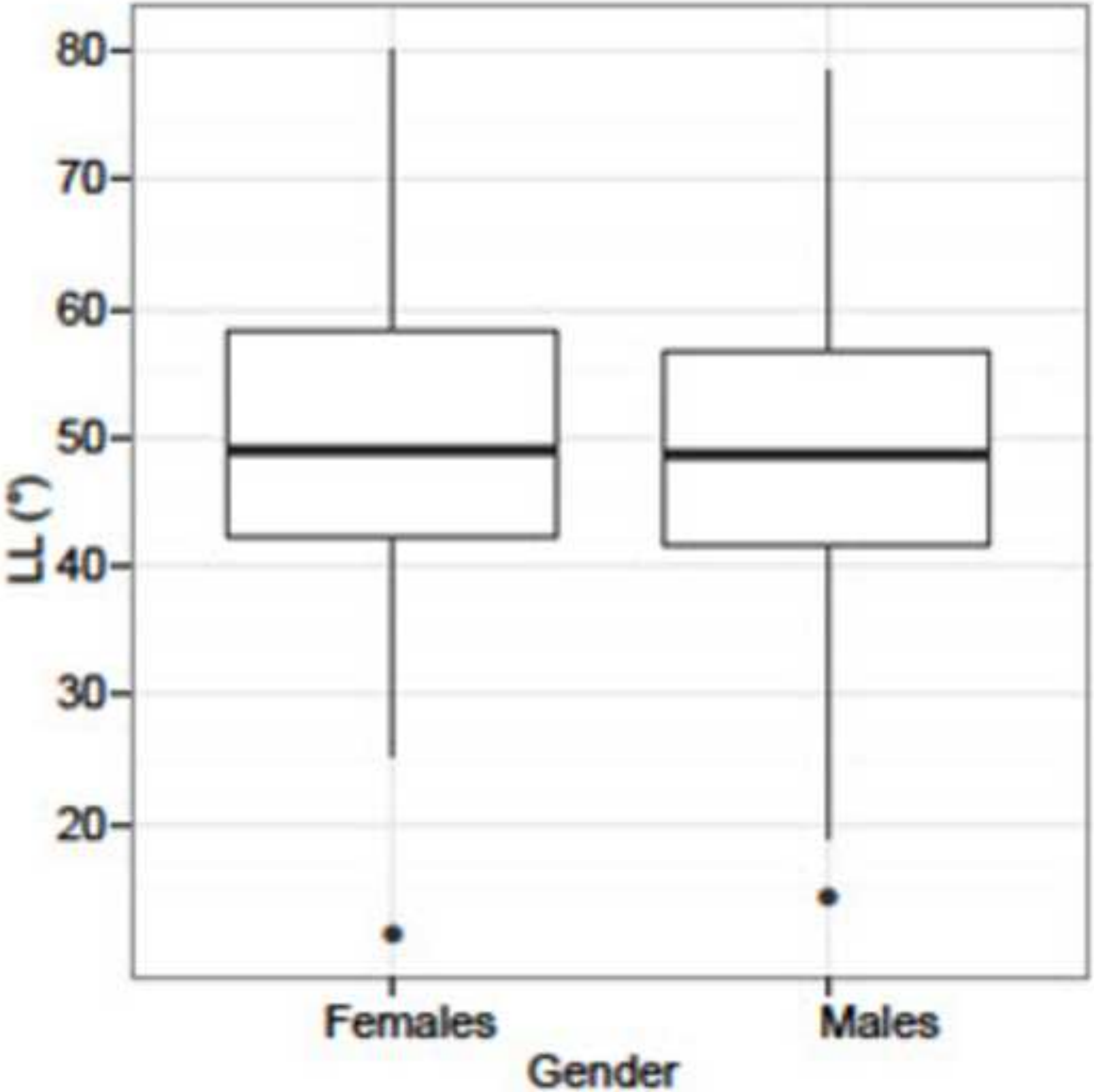

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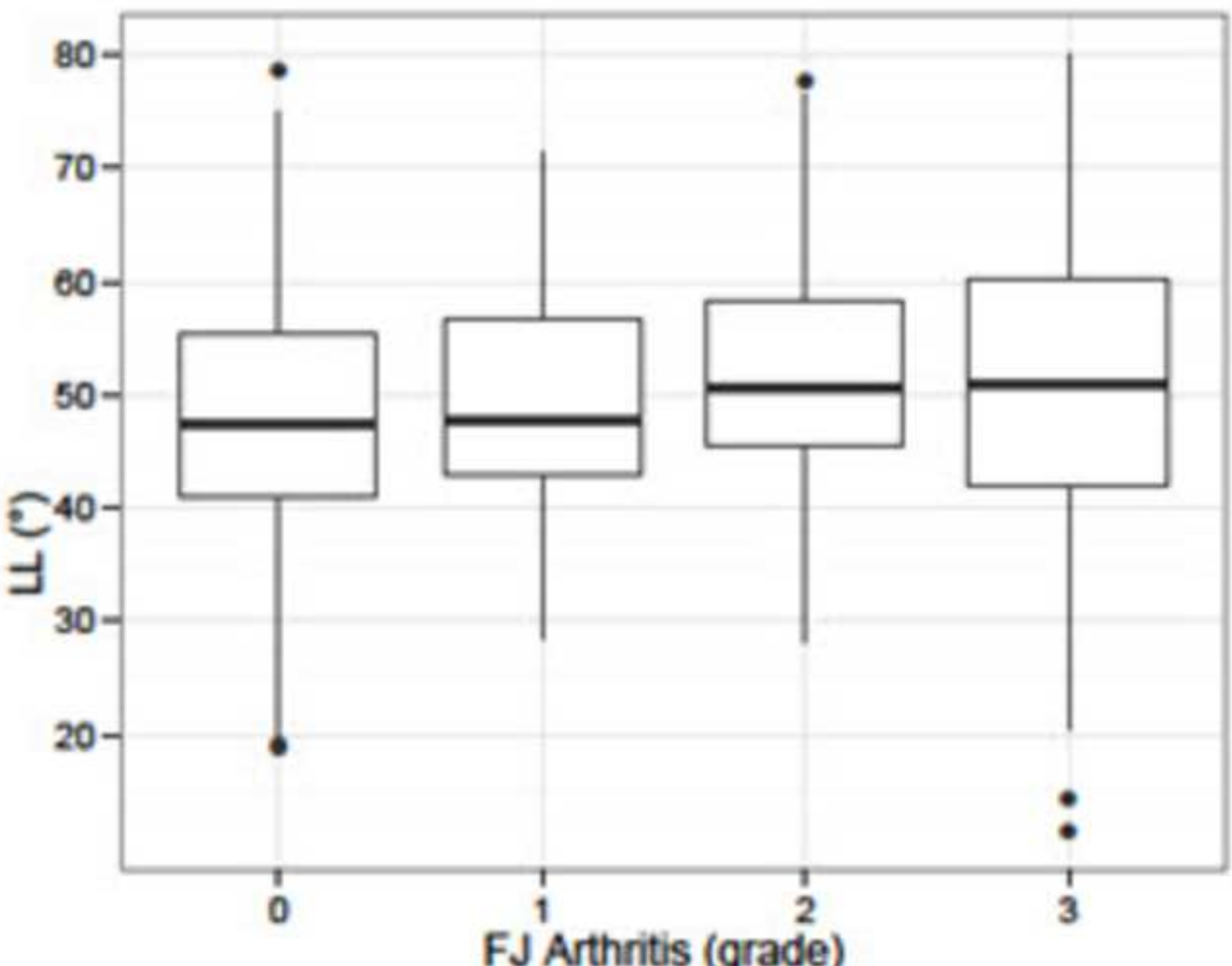

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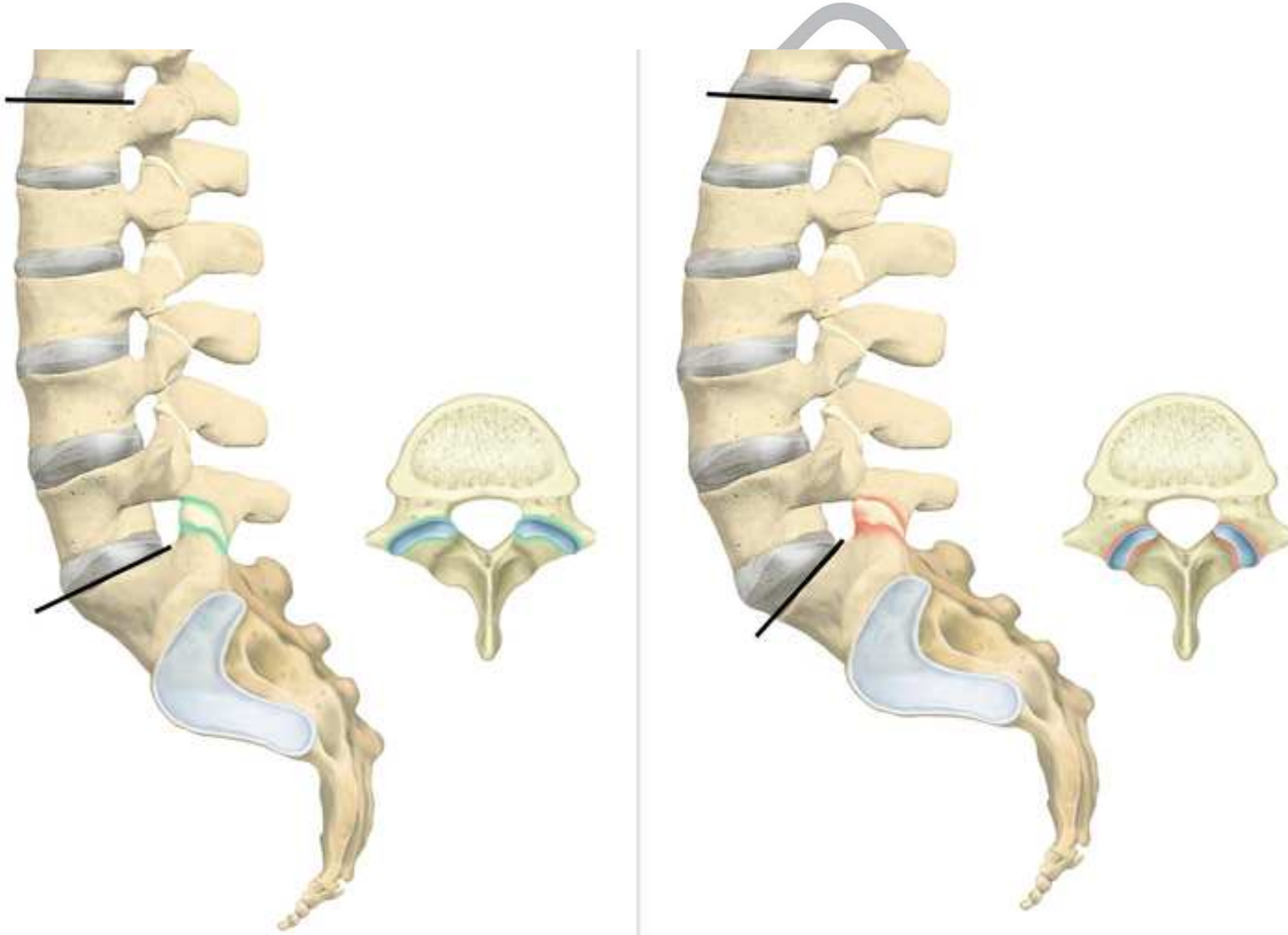

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